

'Science' Applications of Geodetic VLBI

John Gipson
NVI, Inc/NASA GSFC
7th IVS TOW Meeting
Haystack, MA

May, 2013

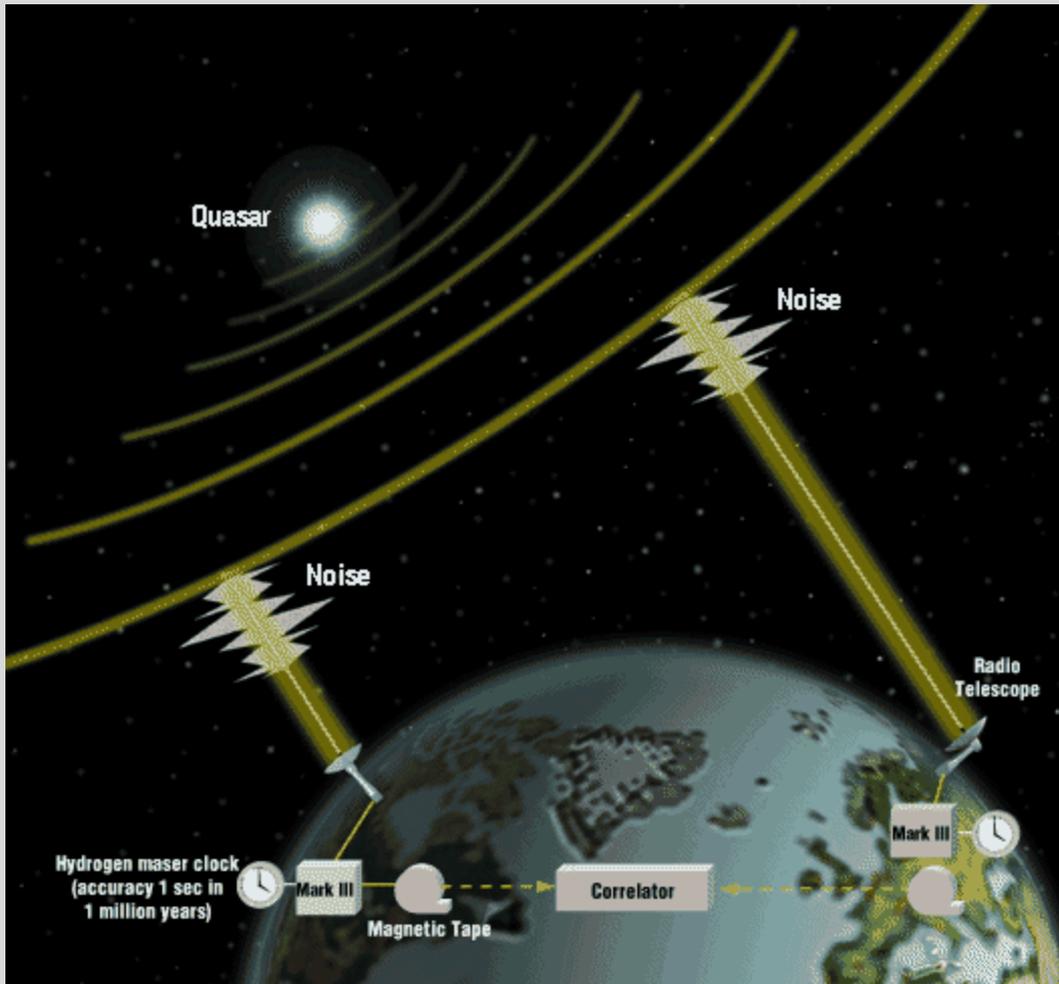
Present some cool things that VLBI contributes to.

Disclaimer:

I claim no originality in the results or in anything that I present unless I explicitly say so.

I have shamelessly stolen from other people. If I remember I will try to give credit.

Overview of VLBI



The VLBI measurement technique consists of measuring the difference in arrival time of a signal from a distance source at two different VLBI antennas. This difference in arrival time is called the 'delay'.

The delay is influenced by anything that effects the propagation of the radio wave or that changes the path.

TRF, CRF, and EOP

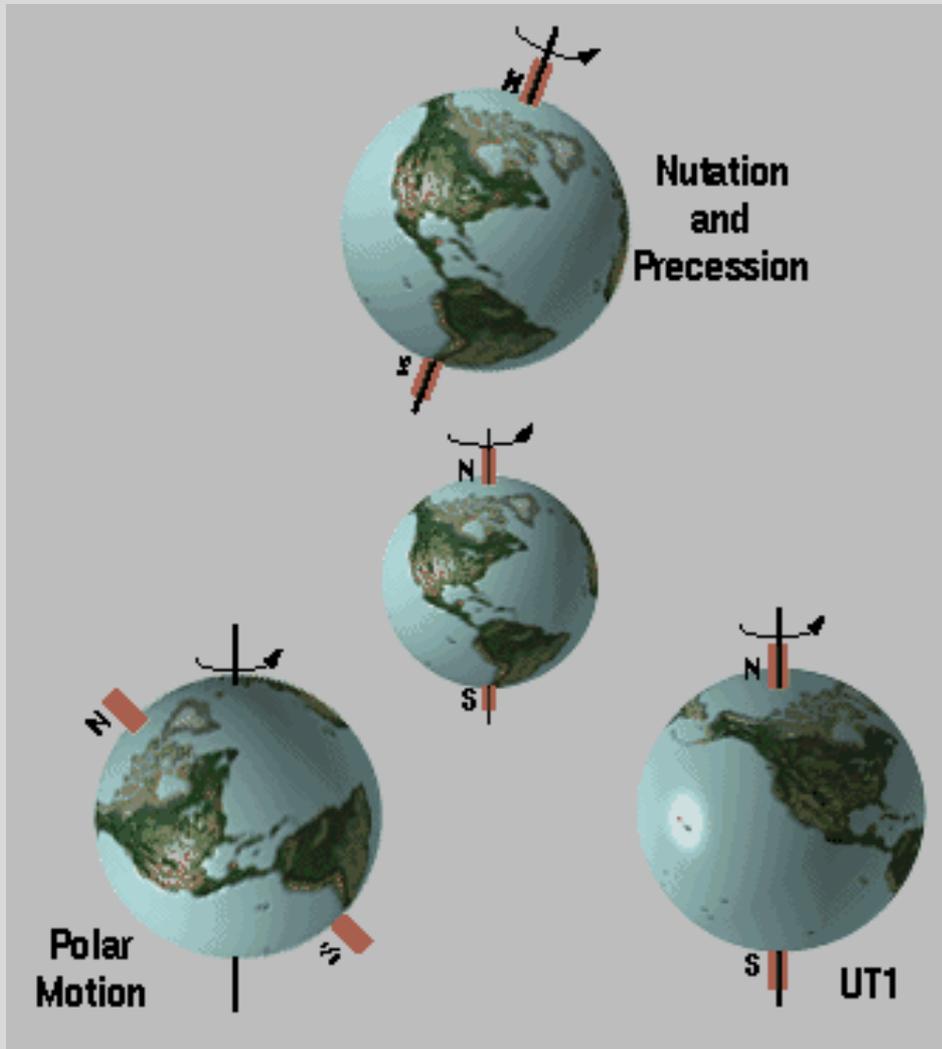
The VLBI stations are part of the Terrestrial Reference Frame.

The Quasars are part of the Celestial Reference Frame.

The TRF is connected to the CRF by Earth Orientation Parameters (EOP).

I will say a few words about all three.

Components of EOP



Nutation/Precession refers to the orientation of the spin axis in inertial space. The difference between precession-nutation is time-scale and origin of the effect.

Polar motion refers to the location of the spin-axis in an Earth fixed frame.

UT1 measures the rotation of the Earth about the spin axis.

LOD=Length of Day is the time derivative of UT1.

Variation in Earth Rotation

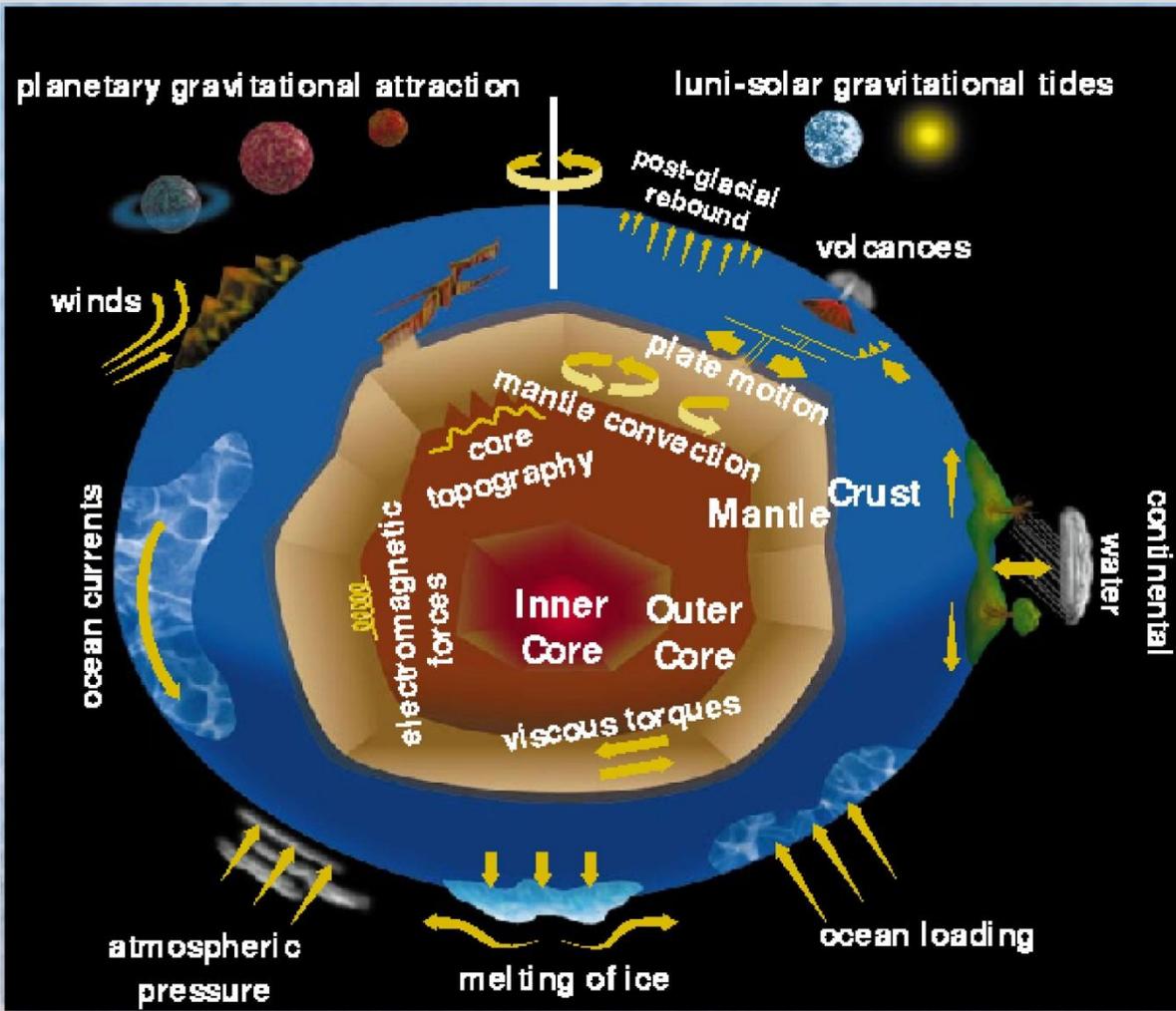


Because of **Conservation of Angular Momentum**, variations in Earth Rotation are caused by:

1. Exchange of Angular momentum between the Solid Earth-Atmosphere-Oceans.
2. External forces due to:
 - Sun
 - Moon
 - Planets
 - Other bodies (negligible)

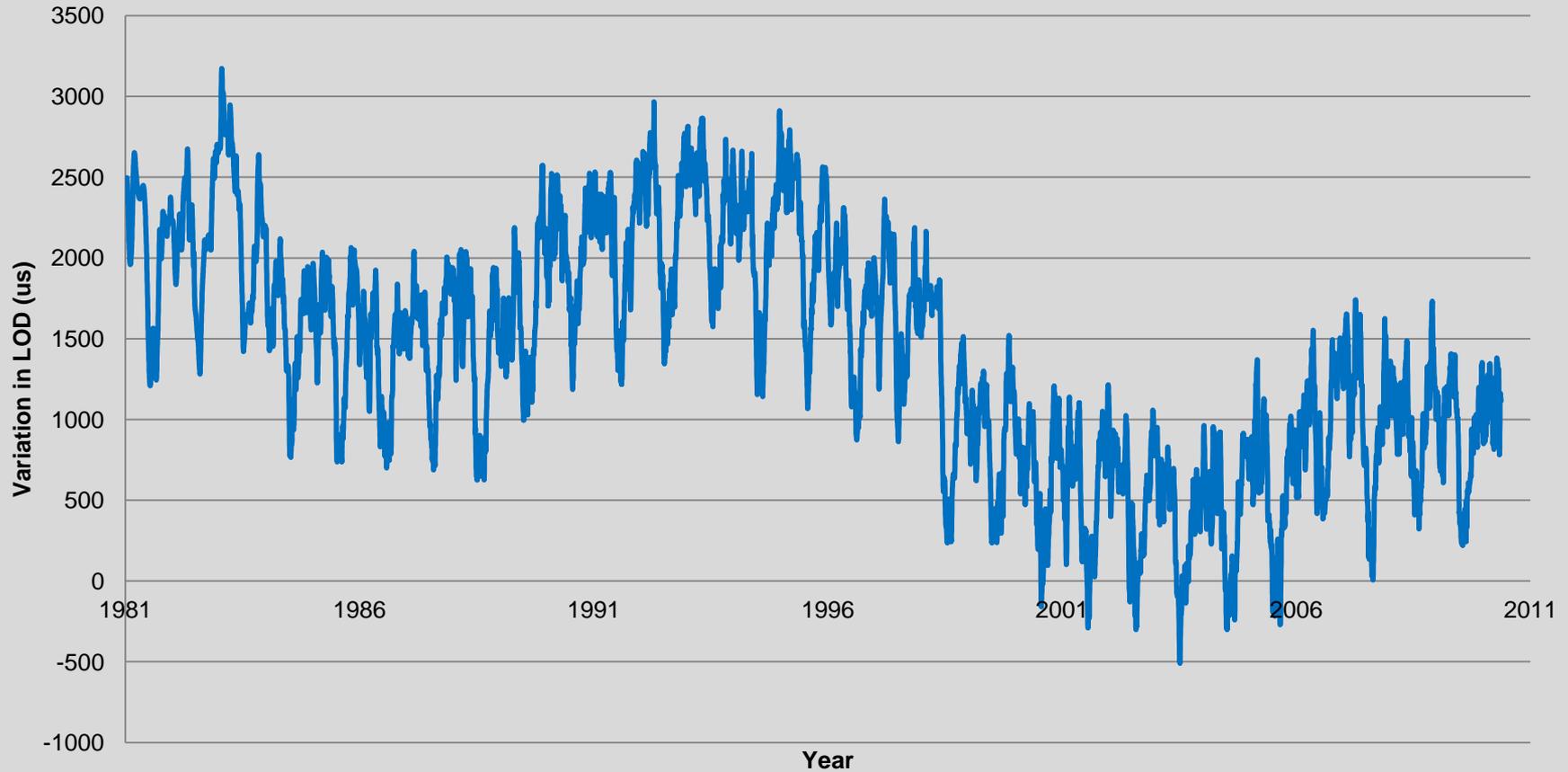
That's it.

Earth Rotation

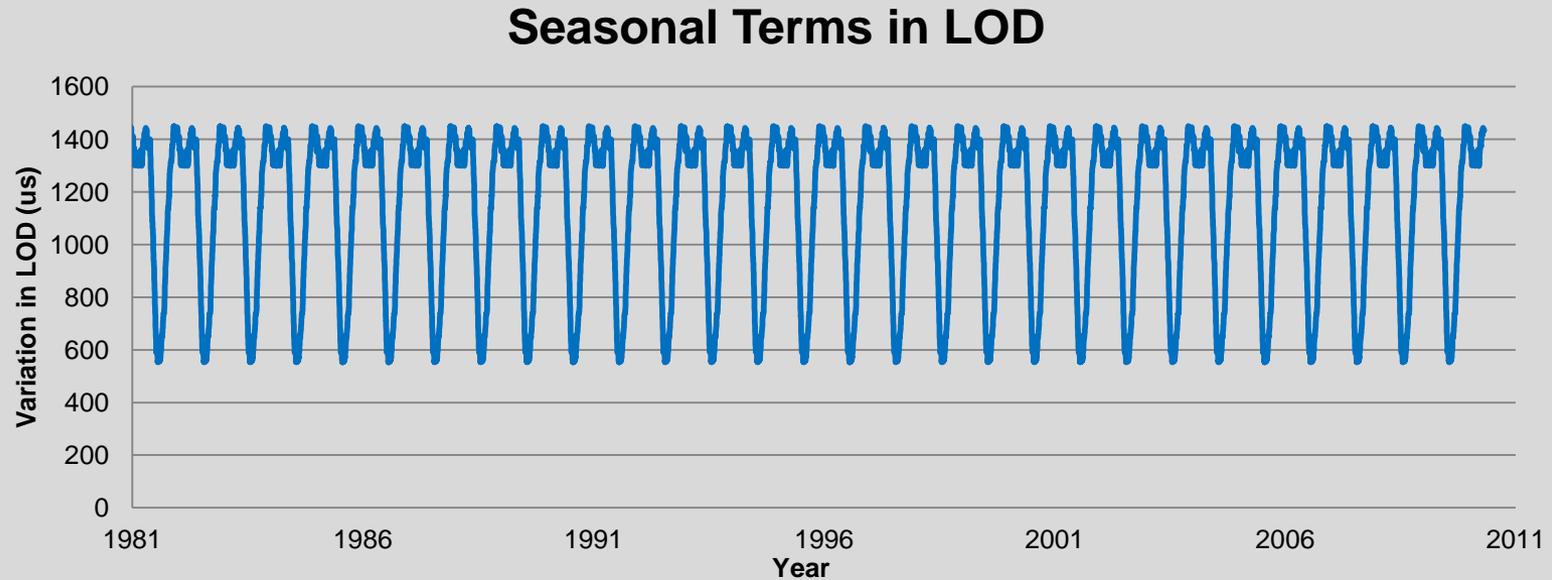


Variation in Earth Rotation

VLBI Measured Length of Day (LOD)

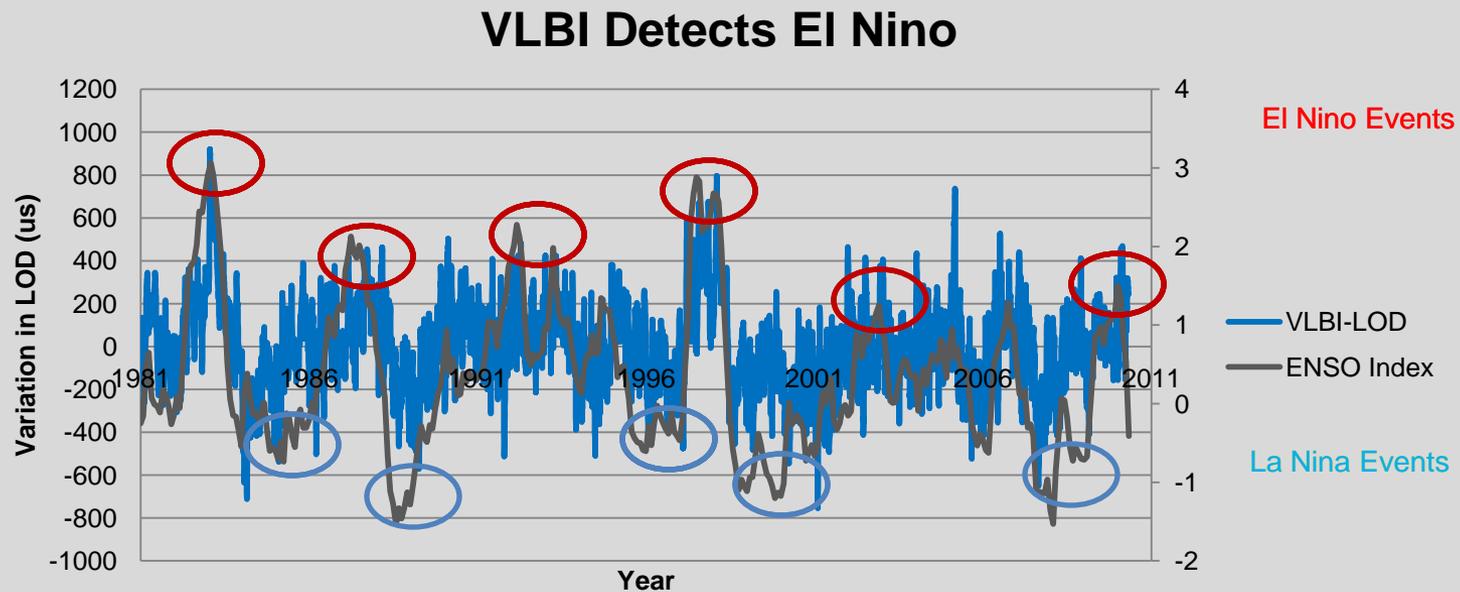


Variation in Earth Rotation



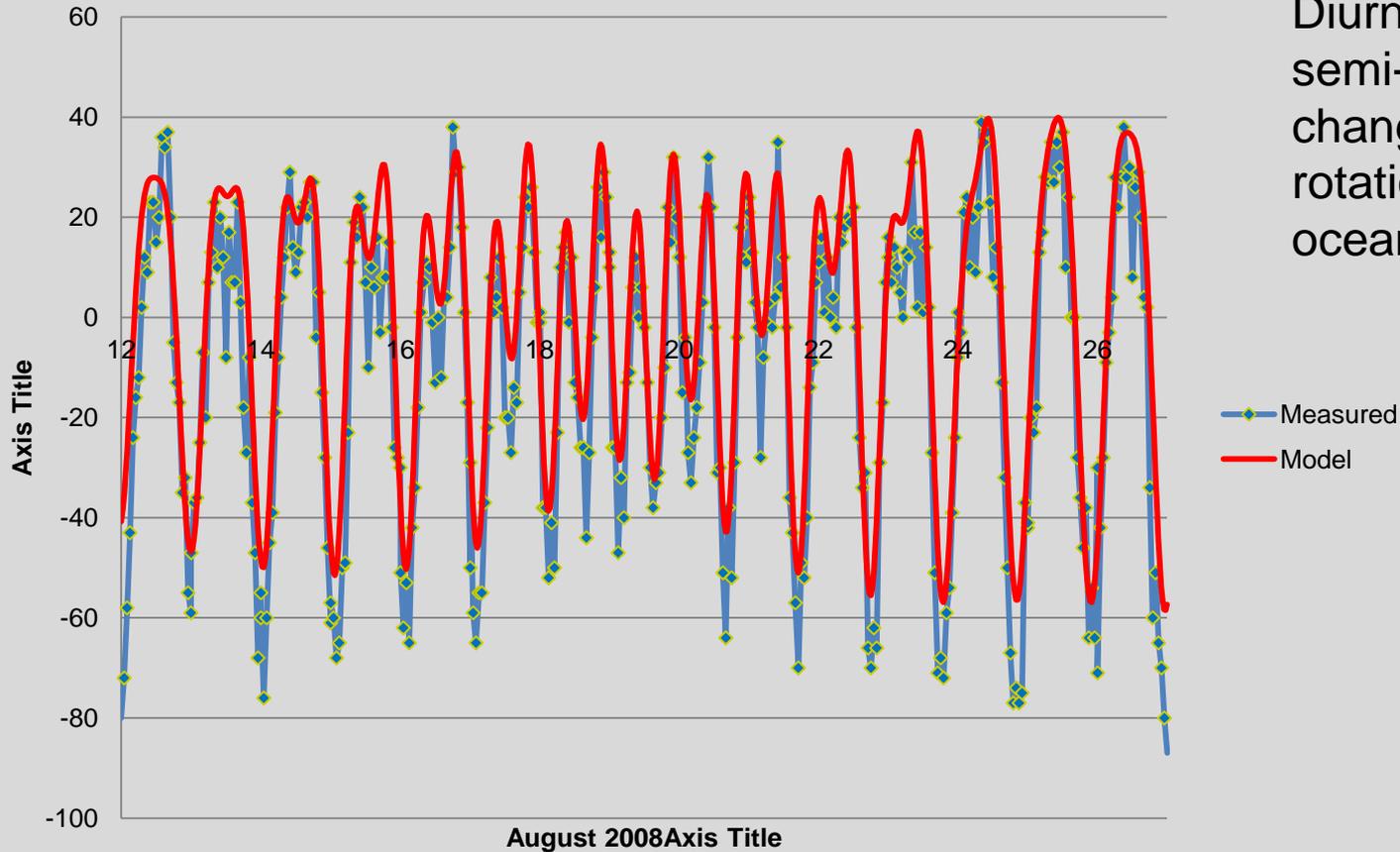
Days are longer (by 800 us) in Northern Hemisphere Winter because of Winter Storms!

Variation in Earth Rotation



High Frequency EOP

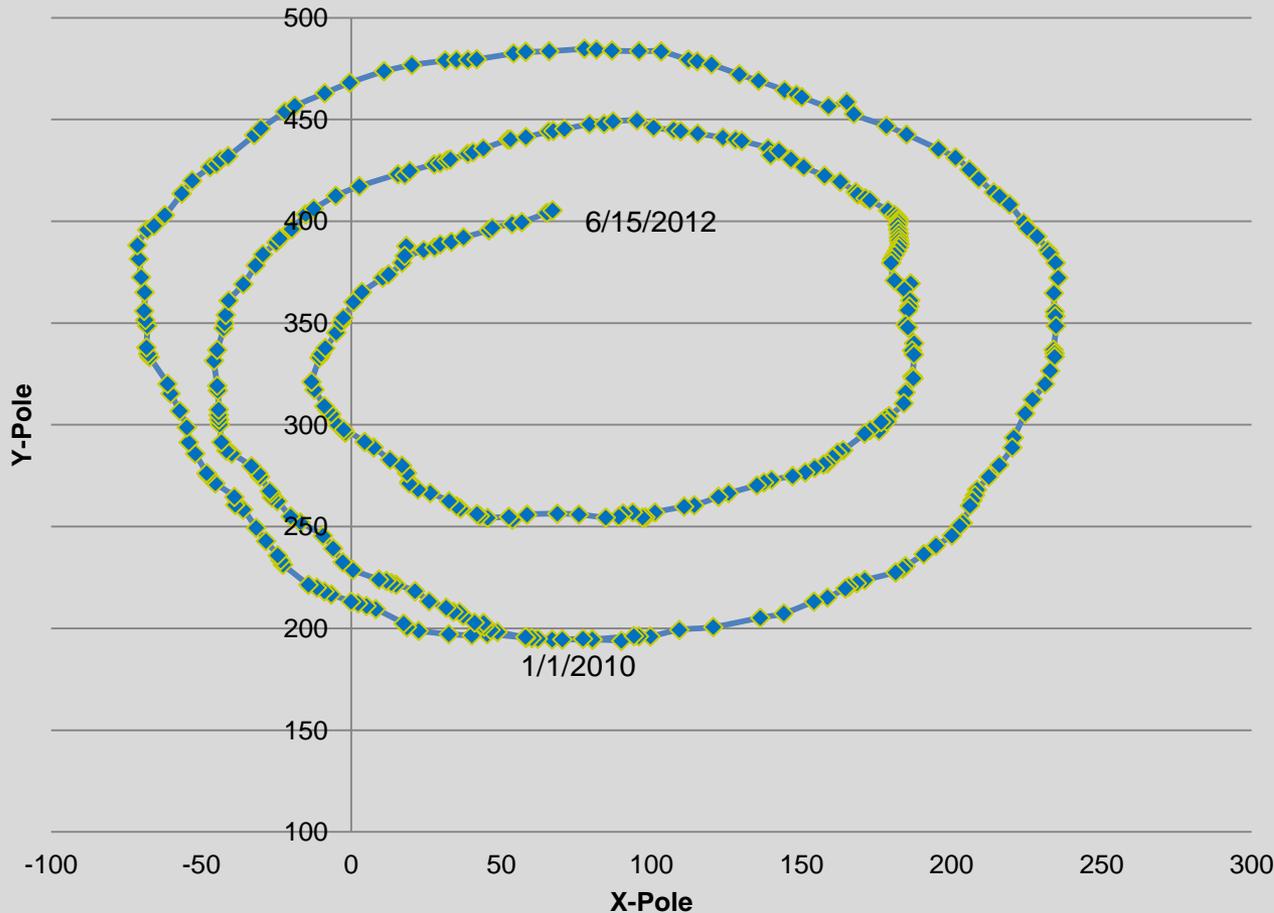
High Frequency Variations in UT1 During CONT08



Diurnal (daily) and semi-diurnal (12 hour) changes in rate of rotation are due to ocean tides.

Polar Motion

Polar Motion from 1/1/2010-6/15/2012



The North Rotation Pole wanders in a roughly circular fashion with a period of ~435 days.

This is called the Chandler Wobble.

The size of the wander is about 12M, or roughly half the size of a baseball diamond.

Response of Earth to Torques

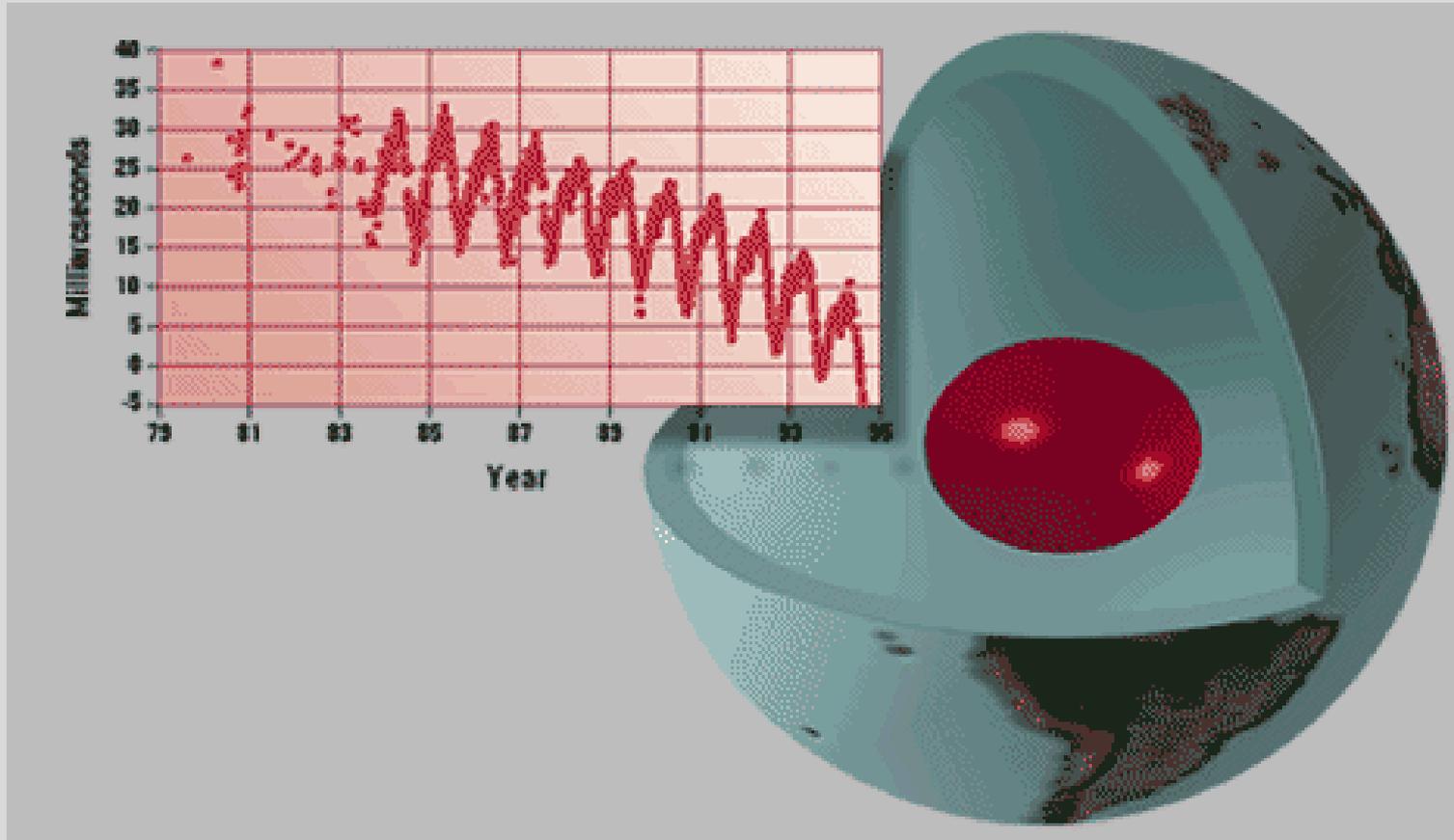


The response of the Earth to External Torques gives information about the internal structure of the Earth.

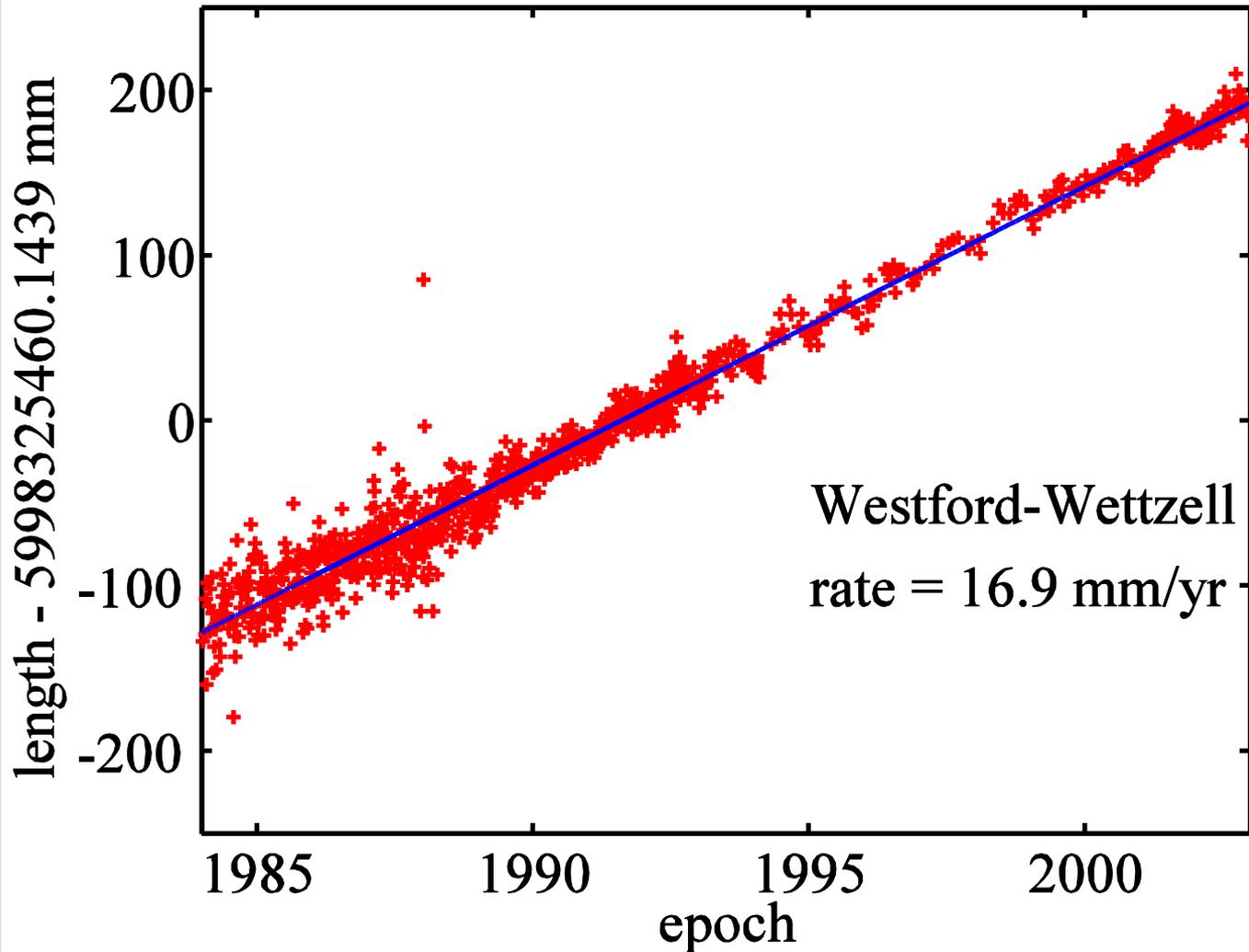
For example, you can easily tell if an egg is hard-boiled or raw by spinning it.

Any volunteers?

Nutation as Probe of Interior



Baseline Length

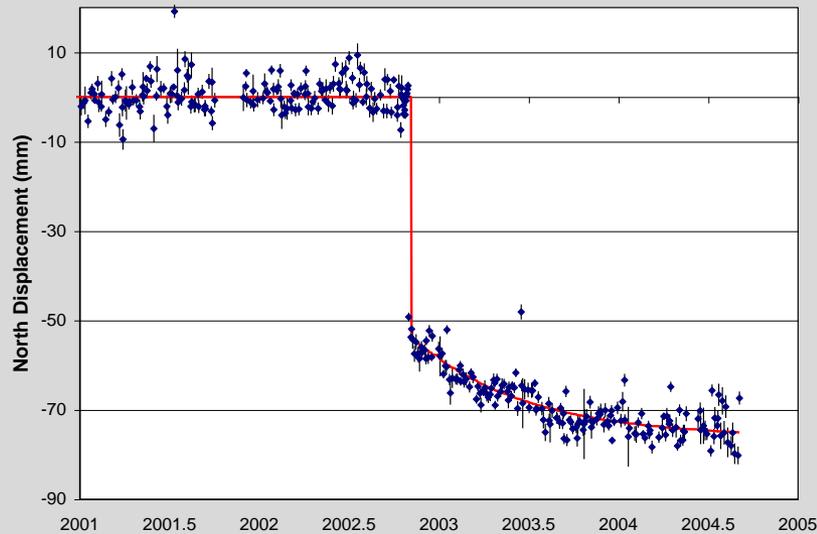


Measurements such as these were the first proof of continental drift happening at the current time.

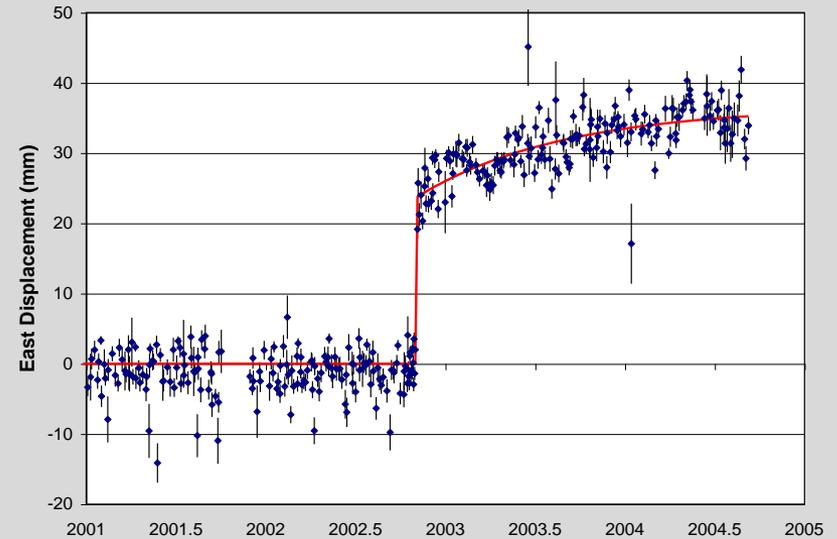
Earthquake Induced Motion

Gilcreek Displacement following the 2002 Denali Earthquake

North

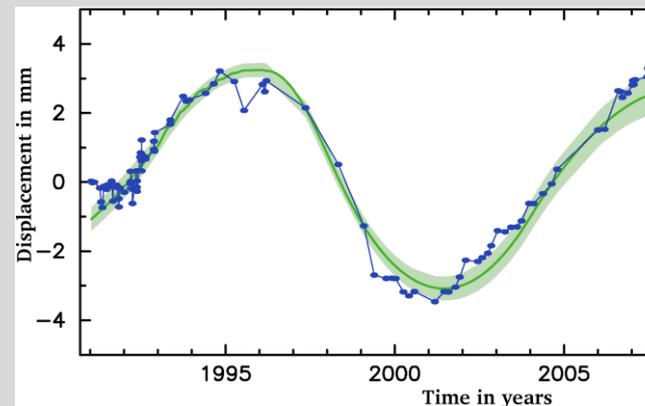
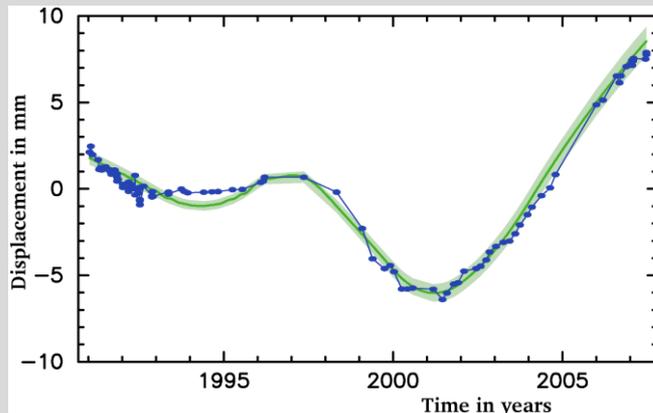


East



Anomalous Station Motion

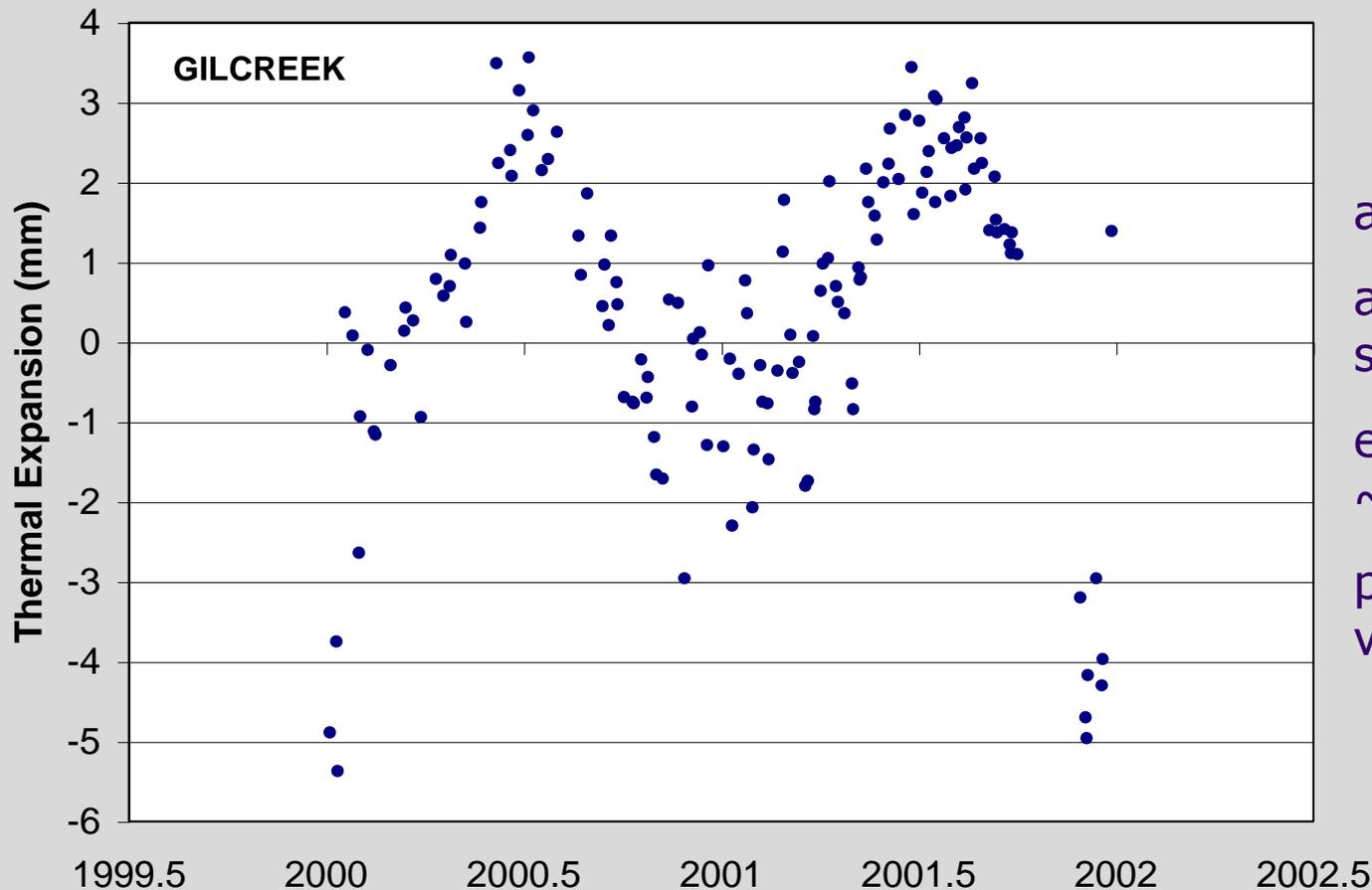
Nonlinear motion of the station PIETOWN (New Mexico)



North and East motion (blue) from measured tilt variation of the antenna compared with the position of the antenna estimated from VLBI analysis (green smoothed curve).

Caused by Tilt of the Antenna Pad

Thermal Deformation of Antennas



antenna height $\sim 15\text{m}$

annual temperature swing $\sim 40\text{ K}$,

expansion coefficient $\sim 1.2 \times 10^{-5}$ \Rightarrow

peak-to-peak variation $\sim 7\text{ mm}$

Terrestrial Reference Frame (TRF)



- Defines the positions and velocities of a set of reference sites over the Earth at a particular epoch.
- Current official TRF is ITRF2008. Epoch is 2005.0. Derived from VLBI, GPS, SLR, and DORIS contributions. Positions for 118 VLBI sites.
- Accounts for current plate tectonic motions, past earthquakes, rail repairs, etc.
- Does not account for earthquakes, etc, after 2008.0 (Chile, Japan). So we have to keep monitoring.
- Next TRF IS ITRF2013.

TRF Goals and Motivation

- Goal is to have
 - 1 mm precision in position.
 - 0.1 mm/yr in velocity.
- Current networks can not achieve this, but ~~VLBI210~~ (oops, VGOS) gets close.
- The TRF allows you to connect observations over space and time.
 - Important for science—monitoring sea level rise, melting of ice-caps, etc.
- Example: If you have a house on the beach, and the water is rising, without the TRF you don't know if:
 - The sea level is rising.
 - The land is sinking.

Terrestrial Reference Frame (TRF)



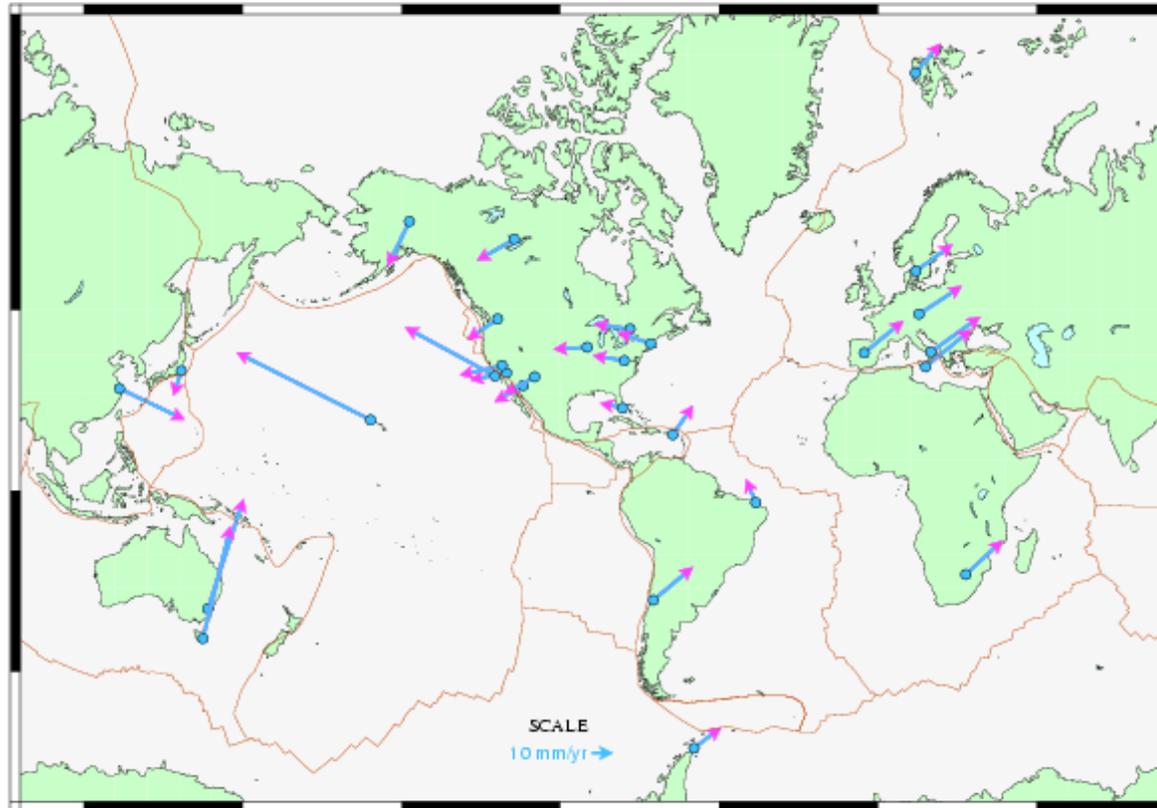
- Contributions from VLBI, GPS, SLR, and DORIS
 - VLBI – scale of TRF, nutation, UT1-UTC, polar motion
 - GPS – polar motion, densification
 - SLR – center of mass, scale of TRF
 - DORIS – global coverage

Each technique has pluses and minuses.

Scale is set by VLBI and SLR.

Terrestrial Reference Frame (TRF)

Selected VLBI Velocities

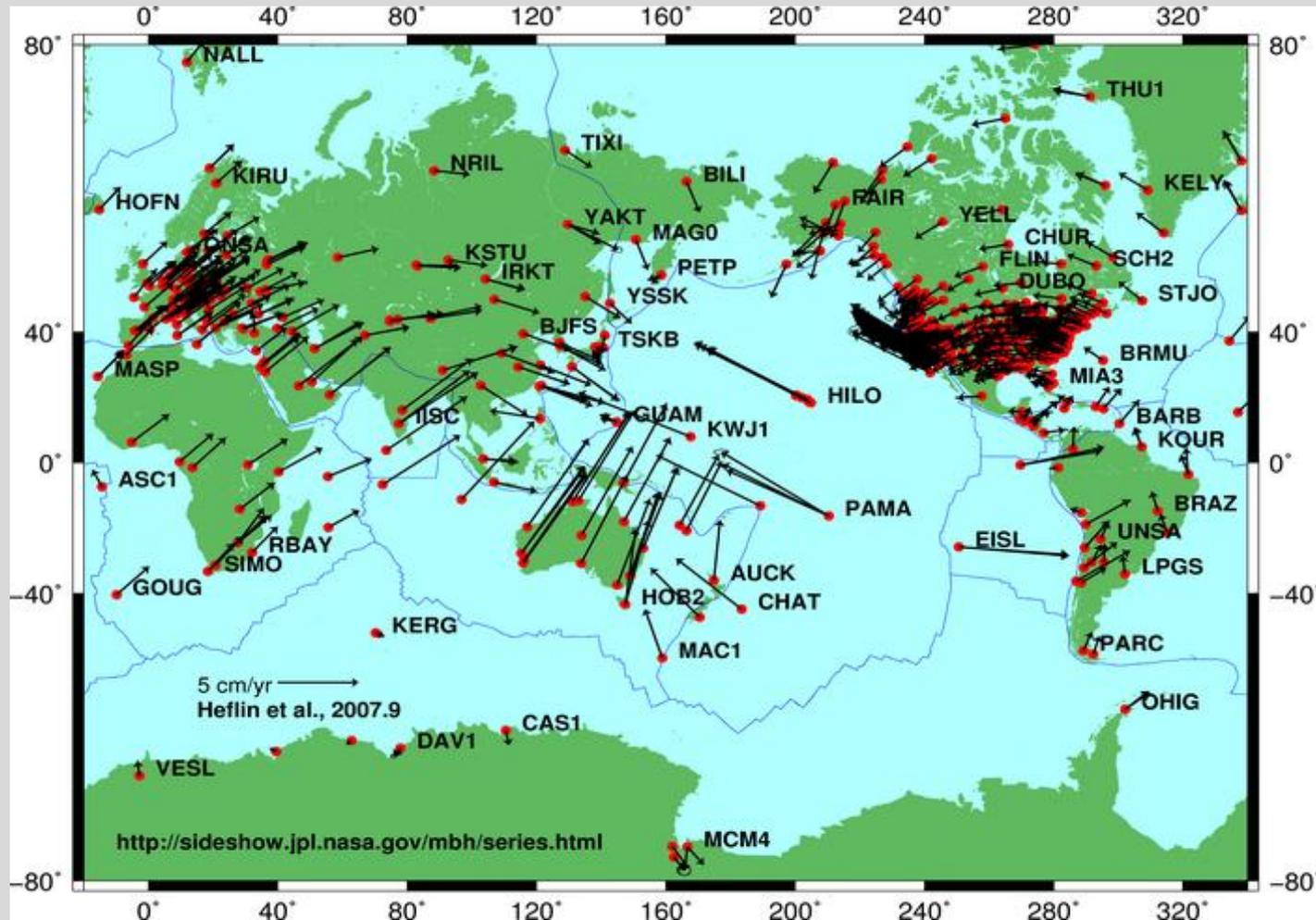


NUVEL1A-NNR reference frame.

1988/01/01

Terrestrial Reference Frame (TRF)

Selected GPS Velocities



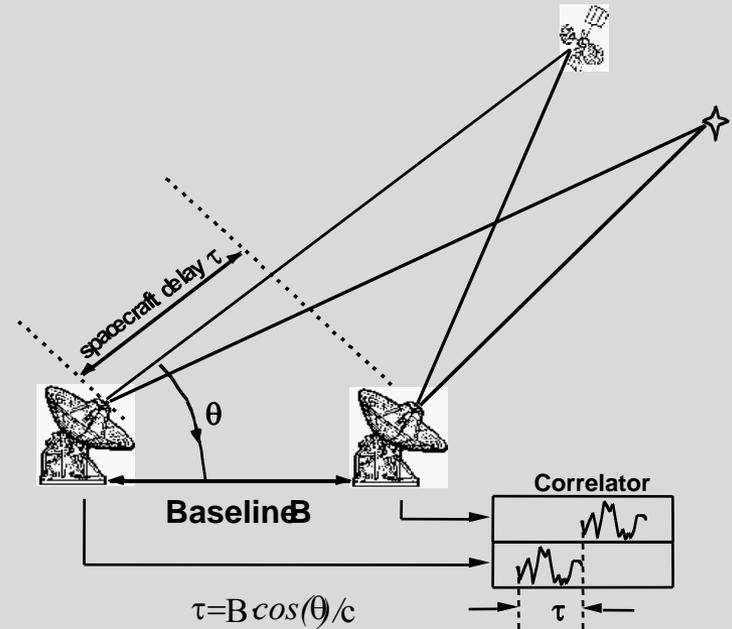
Celestial Reference Frame

- A set of coordinates (RA and Dec) of 'fixed' distant objects (stars, galaxies, quasars, etc).
- First CRF's were optical -- catalogs of star positions.
- In 1995, the first International Reference Frame (ICRF) of VLBI radio source positions was generated and became official Jan. 1, 1997.
- ICRF2 was generated in 2009 and became the official CRF on Jan. 1, 2010.

ICRF & Spacecraft Navigation

By doing VLBI on a spacecraft and on near-by quasars you can determine the angular position of the spacecraft.

This is routinely done by JPL for interplanetary and deep space missions



ICRF2

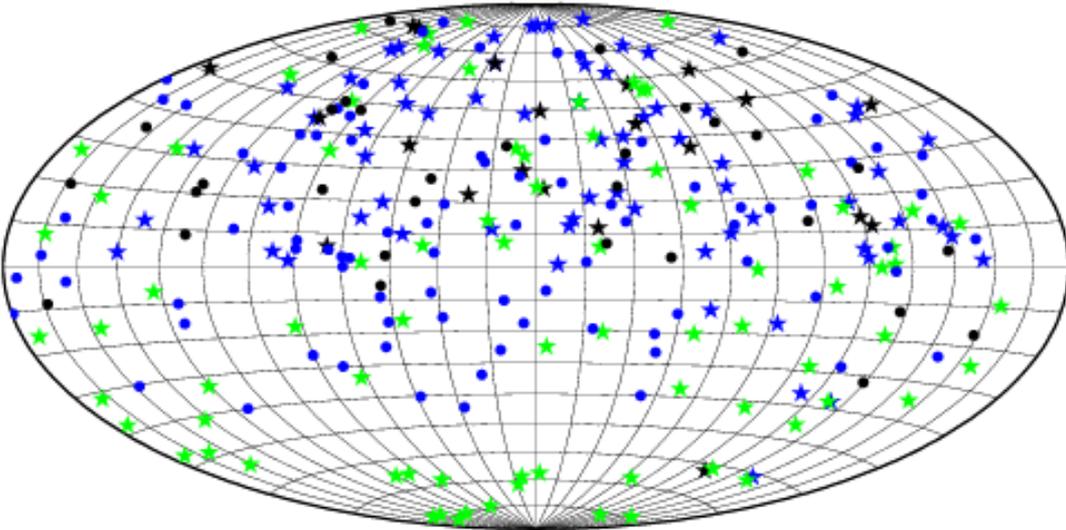
- ICRF suffered from unstable ‘defining’ sources and uneven sky distribution of defining sources.
- The 295 ICRF2 defining sources were chosen based on historical stability, minimal source structure, and even sky distribution.
- Only 97 of the 212 ICRF defining sources were considered suitable as ICRF2 defining sources.
- 3414 total sources
 - 1448 observed multiple times.
 - 1966 observed only once (mostly VLBA Calibrator sessions).

ICRF Comparison

	ICRF (1995)	ICRF2 (2009)	Today (2013)
# VLBI Observations	~1.6 million	~6.5 million	>8.5 million
# Defining Sources	212	275	
# Total Sources	608	3414	3594 X-S sources. 119 X-band only
Noise Floor	~250 μ as	~40 μ as	
Axis Stability	~20 μ as	~10 μ sec	

ICRF1

Total CRF Monitoring Sources

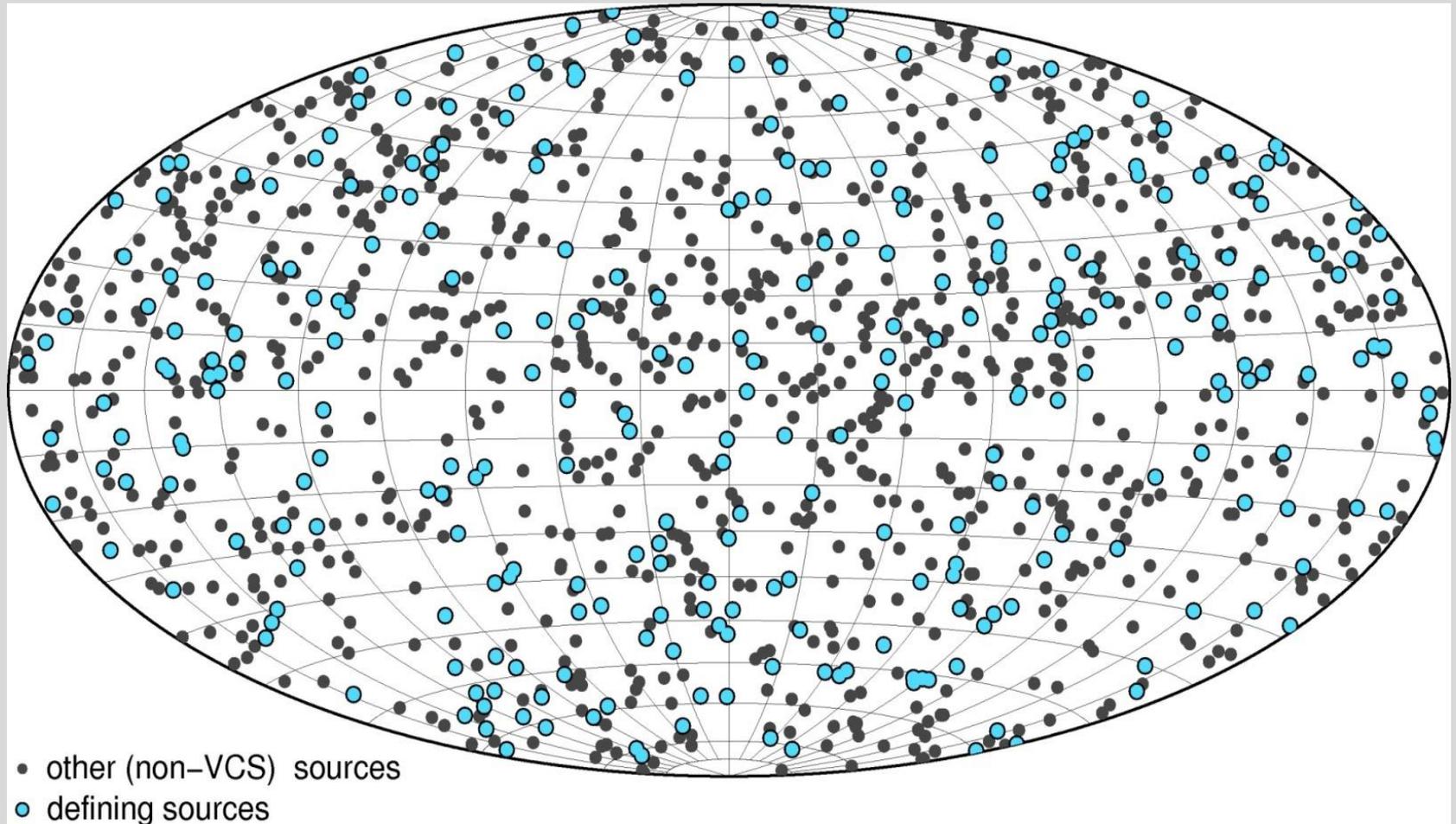


★ 74 Stable ICRF
● 89 Stable other

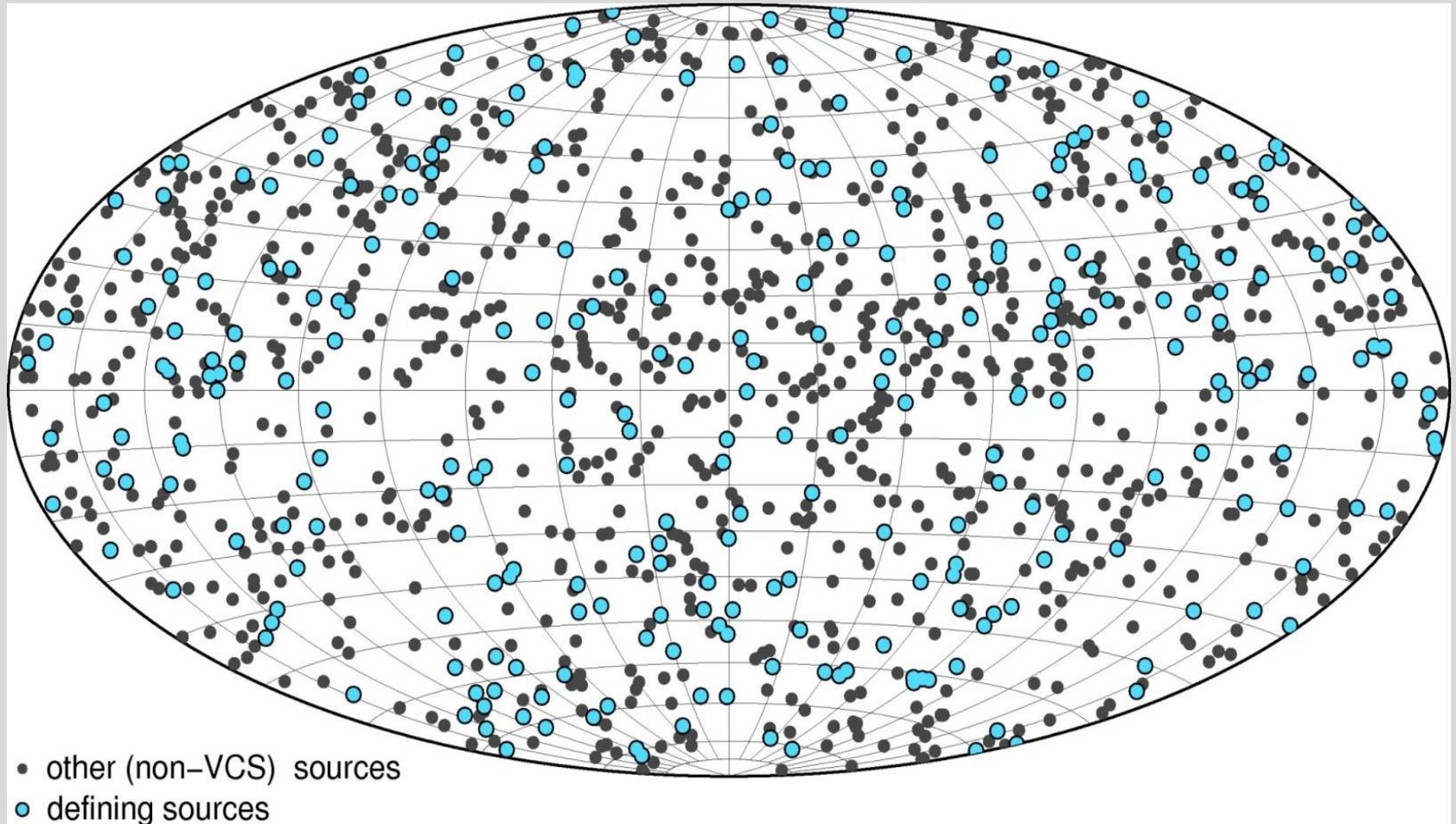
★ 25 Potentially stable ICRF
● 36 Potentially stable other

★ 83 Other ICRF defining

ICRF2



ICRF2



ICRF2

1217 ICRF2 Sources (Non-VCS)

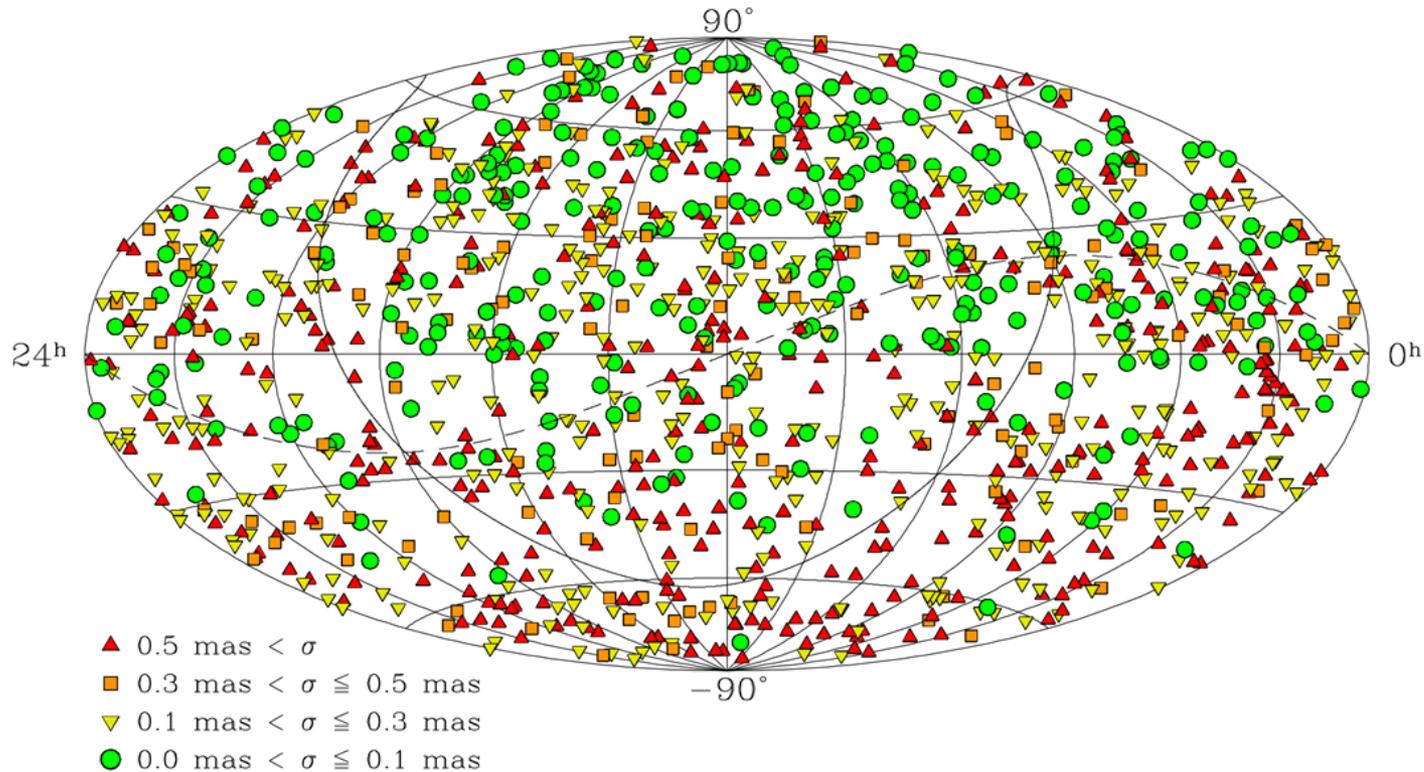
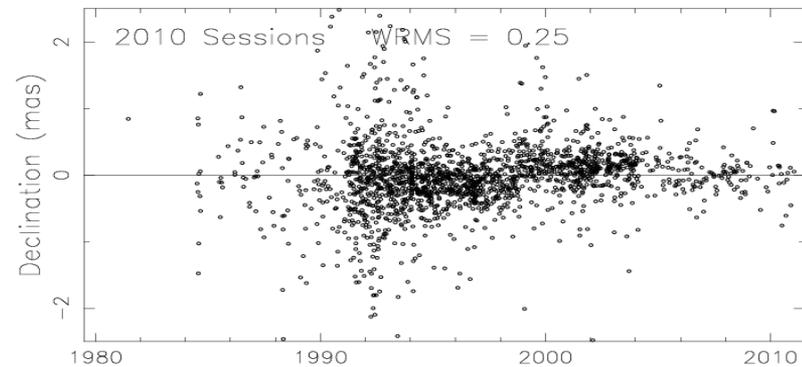
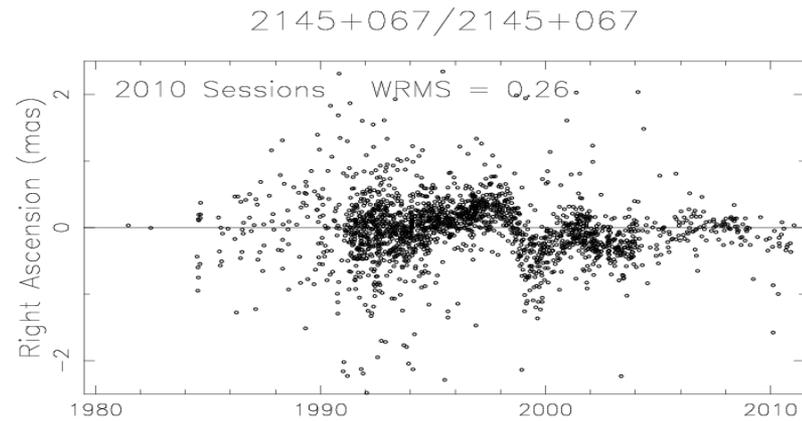
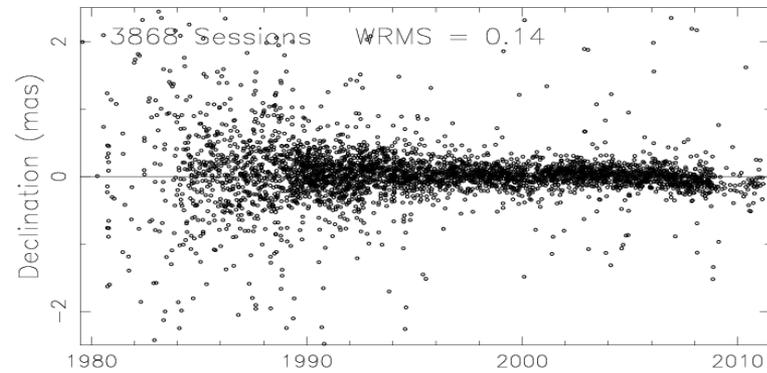
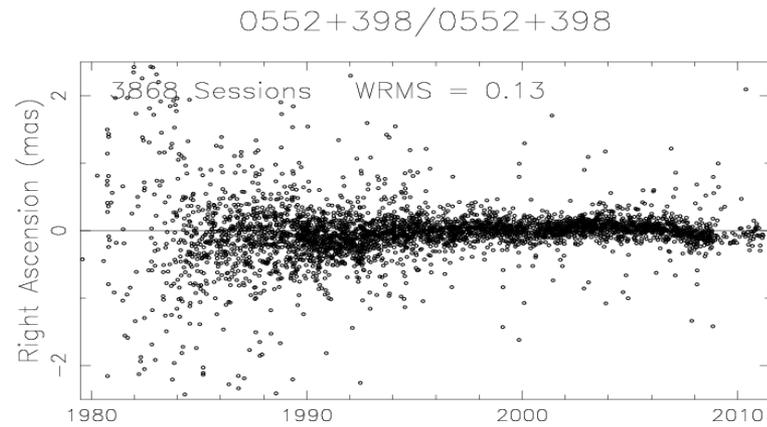


Fig. 3 – □ Distribution of the 1217 ICRF2 Non-VCS sources on an Aitoff equal area projection of the celestial sphere.

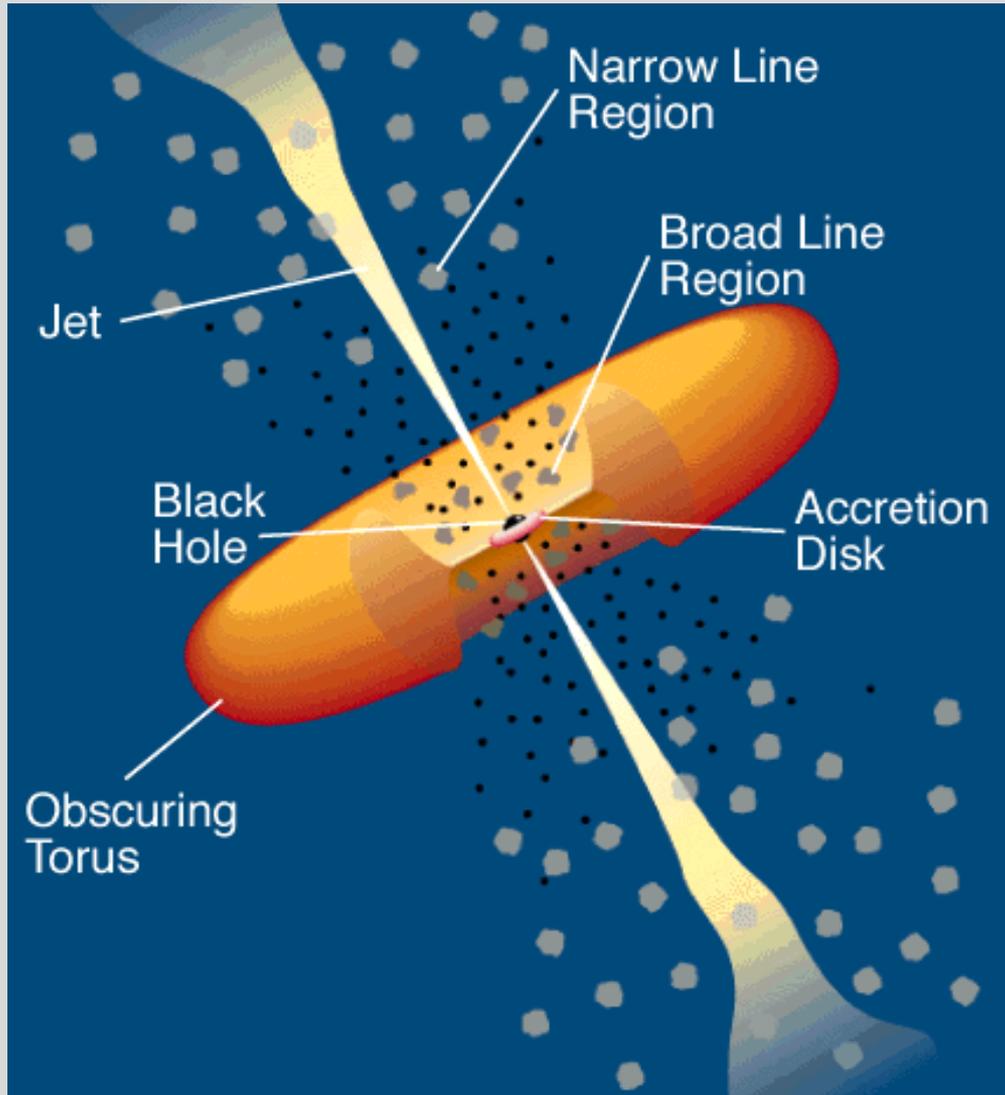
'Unstable' sources



'Stable' ICRF2 Source



What Does a Source Look Like?



In VLBI we observe the jets.

Different parts of the jets radiate at different frequencies.

The higher the frequency, the closer to the core.

ICRF3

ICRF3 is in the preliminary stages. Goal is to have it accepted in 2018.

Will need to consider 'secular aberration drift'.

- Caused by our circular motion around the galactic center.
- Streaming motion of all extragalactic sources towards the galactic center at 4-6 μ asec/yr for sources at the galactic poles.

ICRF3

Closely related project is GAIA—which will survey optical position of 1-billion stars.

ICRF3:

- Will re-observe all sources that have only been observed once or twice.
- Will pay particular attention to VLBI-optical ties.

Conclusions

VLBI is a fascinating technique that provides information to help build a better TRF and the CRF. These are essential in Geodesy and Geophysics, Astrometry, Spacecraft Navigation and other areas.

VLBI is an important contributor to many areas of science.

The next generation of VLBI stations will provide even better results.